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To analyze the modes of muscle failure during pushups in active duty women determining a single "weak link" in performance multiple modes of failure.
25 U.S. Army active duty women were prospectively studied. Each participated in eight sessions, separated by a minimum 48 hours, consisting of stretching warm ups then prefatigue of a specific muscle group to muscle failure with a predetermined exercise.. The initial session set a baseline without prefatigue, the following sessions prefatigued the trapezius, latissimus dorsi, deltoid, pectorals, biceps, triceps, and abdominals.
Studied 25 women, mean age of 33.5 yrs (23-50 yrs), 19 enlisted and 6 officers with a mean weight of 135.9 lbs (90-180 lbs). Baseline mean was 22 pushups (11-40). Prefatigue of pectorals gave a mean of 9 pushups (2-26), triceps mean 11 pushups (2-25), deltoid mean 15 pushups (0-30), abdominals mean 16 pushups (0-29), biceps mean 17 pushups (8-29), latissimus dorsi mean 17 pushups (9-31), and the trapezius mean 19 pushups (6-32).
Prefatiguing of the pectorals and triceps give a significant decrease in pushups compared with other muscle groups (p 0.0005).

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INTRODUCTION

Females have less upper body strength than males. In both isometric and isokinetic testing, female upper body strength values have ranged between 55 and 75% of male values (6, 11). Even when lean body mass and lower extremity aerobic power were equated, the differential in upper body strength continued to exist (4, 14). This is attributed to smaller muscle mass associated with musculature controlling the elbow joint, shoulder joint and shoulder girdle in females. There is also evidence to support that women are more frequently injured in Army basic training, 44.6% versus 29% in males (10). Gender differences in injury rates of military aviators disappeared when size, strength and fitness were controlled (12).

It is important to recognize that the effectiveness of muscle is dependent upon a number of biomechanical, anatomical and physiologic considerations. First, the segmental position of the upper arm with respect to the shoulder joint axis of rotation determines the direction of the muscle force, as well as the force moment arm (1). The muscle moment arm influences the effectiveness of the muscle force to either produce observable movements (longer moment arm) or to stabilize/dislocate a joint (shorter moment arm). By changing the angular position of the shoulder joint, the muscle torque producing shoulder abduction may either increase or decrease, even though the absolute value of the muscle force remains the same. The effective muscle force which holds the humerus in the glenoid fossa may decrease to the point of creating laxity in the joint or may increase so that increased compressive or shear forces restrict movement and lead to increased stress on other joint structures. There is evidence that when the shoulder is abducted and externally rotated, both heads of the biceps brachii contribute to the compressive forces that are the main anterior stabilizing mechanism for the shoulder joint (8).

A second consideration related to strength and injury potential is muscle imbalance. Muscle imbalances between opposing muscle groups controlling a joint have been linked to increased incidence of injury. One study has examined shoulder ratios in a small number of untrained women and men, but no relationship between either performance or injury was posited (2,9). Many acute and chronic complaints in the shoulder are due to a reduced active stabilization capacity by insufficiently developed shoulder musculature and muscle imbalances, but again the strength values were based on a small number of untrained women and no relationship to performance or injury was tested (13). However, higher shoulder abduction/adduction and abduction/internal rotation strength ratios have been found in shoulders of paraplegics with shoulder impingement syndrome when compared to paraplegics without impingement syndrome. The authors concluded that shoulder muscle imbalance with comparative weakness of the humeral head depressors may be a factor in the development of this syndrome in wheelchair athletes.

A third issue is the development of localized muscular fatigue during the performance of repetitive actions. Fatigue is a continual, time-dependent process that leads up to a failure point. In a multisegmented human body it is important to identify the muscles which are the "weak link" and to recognize that muscular substitution or movement pattern changes may occur during the

fatiguing process. The time occurrence of fatigue is related to the external force produced and the speed at which the movement occurs.

The Army currently utilizes the pushup as an assessment of upper body strength. This test is performed by all individuals in the Army on a biannual basis during the APFT, but the standards for women are much lower than those for men. In spite of the wide utilization of the pushup, there is very little information about the biomechanics of the pushup. On the basis of a complex three dimensional model, a recent study of male subjects demonstrated differences in elbow joint load with changes in hand position during slow pushups, but the effect at the shoulder has not been qualitatively examined (3). The only research study examining female pushup performance quantified the electromyographic (EMG) amplitude response of selected muscles in 10 women who could perform more than 10 pushups, and they reported that the anterior deltoid, triceps brachii, trapezius and pectoralis major were most involved in pushup exercises (7). The external forces produced during the pushup are expected to change with various positions throughout the pushup cycle and to change with a function of speed. Identification of the position of the joints as well as any fatigue-related movement pattern changes would be helpful in identifying the mode(s) of failure in the pushup test. Based on these data and information about shoulder and elbow strength balances, strategies to strengthen the appropriate muscle group(s), to enhance pushup performance and to minimize the risk of injury can be developed.

BODY

Materials & Methods

The second phase of the study will examine how prefatigue of a muscle or muscle group affects the pushup. There will be seven muscle groups prefatigued; the trapezius, the latissimus dorsi, the deltoid, the pectoralis major/minor, the biceps brachii, the triceps brachii, and the abdominals. The subject will then participate in a pushup exercise to muscle fatigue. A different muscle group will be prefatigued at each session. The subject will be asked to participate in seven sessions, each lasting about 30 minutes. There will be at least a 48 hour rest period between exercise sessions.

The order of the muscle group tested will be randomized for each patient to account for the possibility that subjects may experience an increase or decrease in muscle strength over time.

During each session there will be a 15 minute stretching and warmup period. The specific exercises are as follows, the trapezius will be fatigued using shoulder shrugs with 20% of the subject's body weight. The latissimus dorsi will be fatigued using a bent over rowing exercise with 20% of the subject's body weight. The deltoid will be fatigued using an straight arm shoulder abduction, from 0-70 degrees, exercise with 10% of the subject's body weight in each hand. The pectoralis muscle groups will be fatigued with a seated "fly" exercise with the use of an Olympus weight machine set at 20% of the subject's body weight. The biceps brachii will be fatigued using a supination/flexion exercise at the elbow with 5% of the subject's body weight in each hand. The triceps brachii will be fatigued using a triceps extension Olympus weight machine set at 10% of the subject's body weight. The abdominal muscle group will be fatigued using an abdominal "crunch" exercise with the subject on her back with both hips and knees flexed to 90

degrees. The monitor will then demonstrate the exercise to be accomplished. The subject will take 1 minute to familiarize herself with the exercise. The subject will then do the specified exercise to muscle fatigue and then be assisted with two more repetitions. The subject will then have a 2 minute recovery/stretching period. The subject will then participate in a pushup exercise at normal cadence with the arms in a neutral position until failure. Fatigue is described as the inability to rise from the down position, inability to keep up with the cadence or movement of arm position. The number of repetitions will be recorded on the Phase II Data Collection Sheet (see attachment), as well as biplanar video recording of the exercise. The subject will be monitored at all times of the session by a military physician. The exercise will be terminated if there is evidence of pain, over exertion or at the physician's discretion. The investigator will have available prepackaged over the counter non-steroidal anti-inflammatory medication such as Tylenol for muscle soreness, with enough medication to last 48 hours.

All adverse events or side effects will be reported to the Human Use Review and Regulatory Affairs Division.

Results

There were no injuries associated with this study. 29 women agreed to participate in this study and 25 active duty women with a mean age of 33.5 years (Range: 23-50 years) completed the entire protocol. There were 19 enlisted and six officers with a mean weight of 135.9 lbs. (Range: 90-180 lbs.). A baseline was obtained prior to any prefatigue exercises, mean of 22 pushups (Range: 11-40). After prefatiguing of separate muscle groups on separate occasions the following data was obtained, prefatigue of pectorals gave a mean of nine pushups (Range: 2-26), triceps a mean of 11 pushups (Range: 2-25), deltoid a mean of 15 pushups (Range: 0-30), abdominals a mean of 16 pushups (Range: 0-29), biceps a mean of 17 pushups (Range: 8-29), latissimus dorsi a mean of 17 pushups (Range: 9-31) and trapezius a mean of 19 pushups (Range: 6-32). Significant correlation was seen between increasing weight of participant and a decreasing number of pushups ($p<0.01$).

CONCLUSIONS

This study demonstrates that prefatiguing of the pectorals and triceps give a significant decrease in the number of pushups completed by the participants compared with other muscle groups ($p<0.0005$). There is also evidence that the weight of the participant affects the number of pushups performed before and after prefatiguing of muscle groups. No significant differences were seen between the age or rank of the participants in the number of pushups performed. This study shows that exercise programs emphasizing the pectoral and triceps muscle groups could increase the number of pushups while helping to prevent injuries. The study also points to weight control as a potential factor in increasing pushup performance. The next step to analyze these findings would be to set up an exercise program focusing on the pectorals and triceps. This group could then be compared to a group who exercise with pushups only and a control group. The comparison could help identify an exercise program to help soldiers to increase the number of pushups performed while preventing training injuries.

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Data Collection Sheet

NAME	AGE (YR)	WT (lb)	RANK	PREFATIGUE MUSCLE GROUPS (REPS)						
				TRAP	DELT	LATS	PECT	BICEP	TRICEP	ABDS